PARTITIONING OF VOLATILE ELEMENTS DURING CORE-MANTLE DIFFERENTIATION. J. Li [1] and C. B. Agee [2], [1]Department of Earth and Planetary Sciences, Harvard University, Cambridge, MA 02138, U.S.A. li@eps.harvard.edu, [2]agee@eps.harvard.edu

Introduction

While numerous efforts have been taken to study the partitioning of refractory siderophile elements during core-mantle differentiation, volatile siderophile elements have been largely overlooked. The Earth's mantle is depleted in volatile elements relative to primitive solar composition. Some volatile elements may have entered the core, therefore these elements may reveal important information on how the core formed. Moreover, to estimate the bulk Earth inventory of these elements, we must know their behavior during core formation.

Current core formation models based on partitioning of refractory siderophile elements at near-surface pressure found the nearly chondritic nickel to cobalt (Ni/Co) ratio in the Earth's mantle hard to explain. It has been shown that pressure has a dramatic effect on partitioning of Ni and Co between liquid alloy and liquid silicate. Consequently, the enigmatic Ni/Co can be explained by core-mantle equilibrium at high pressure, suggesting core formation from a deep magma ocean [1]. Therefore, it is important to study the partitioning of volatile siderophile elements at high pressures.

Experimental and Analytical Methods

Experiments were performed at pressures of 5, 10, 16 and 20 GPa, under isothermal conditions of 2000°C, with a Walker-style octahedral multi-anvil device. Details of the experiment design and technique can be found in Agee et al. [2]. Starting material was fine powder of abraded Homestead (L5) meteorite, doped with lead(Pb) and copper(Cu). Sample capsules were fashioned from high purity MgO rod.

All experiments contained coexisting immiscible liquids of Fe-rich alloy and silicate. Both liquids, upon quenching, formed discrete relatively large masses of crystals and glass. The average composition of these domains were determined by multiple broad beam analyses using a Cameca electron microprobe.

Duplicate and triplicate experiments were run to check the attainment of equilibrium and the effect of concentration of dopants on partition coefficient.

Results

The influences of pressure on partitioning of Cu, S and Pb are distinct and remarkable. From 1bar to 30 GPa, partition coefficient of S (D_S liquid alloy / liquid silicate) increases by an order of magnitude while that of Pb (D_{Pb}) decreases by comparable magnitude. As a result, D_S/D_{Pb} are expected to change from ~3 to ~300 over this pressure range. Effect of pressure on partitioning of Cu is very small. D_{Cu} remains essentially unchanged with pressure.
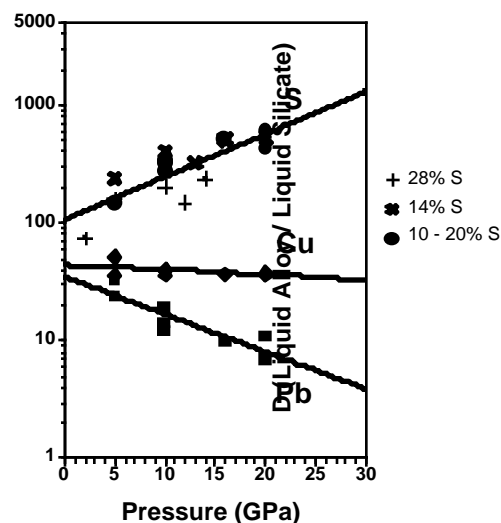

Figure 1. Partition coefficients of Cu, S and Pb (D) versus Pressure (P). Partition coefficients of Cu and Pb are normalized to $D_{Fe}=14$ for direct comparison with required values based on mass balance calculation; and to 10 wt% S in the liquid alloy as the concentration of S in the liquid alloy varies between 10 and 20 wt%. Lines are least-squares fits for the experimental data of the form $D = A*e^{(B*P)}$, where A and B are constants.

Discussion

Estimated mantle abundance of Pb is higher than that of S by an order of magnitude. Since Pb is more volatile than S during condensation and evaporation, bulk Earth would get less Pb than S during accretion, and lose more Pb than S during any possible post-accretion heating process. Hence the overabundance of Pb over S is most likely a result of core formation. In order to produce an overabundance of this magnitude, D_S/D_{Pb} has to be at least 10. At 1bar, D_S/D_{Pb} is only ~3. Therefore, our new results on partitioning of Pb and S exclude core-mantle equilibrium at 1 bar and argue for core formation at elevated pressure.

Partitioning of Ni and Co suggests core formation from a deep terrestrial magma ocean down to the mid-mantle. At this pressure, D_S/D_{Pb} is big enough to produce the observed overabundance of Pb relative to S. Assuming bulk Earth volatile element composition falls on the trend formed by the majority of volatile lithophile elements, (known as volatility trend, VT), core-mantle equilibrium at ~30 GPa would result in a mantle more depleted in Cu, S and Pb than observed (Figure 2). One way of fixing this problem is by addition of a late veneer after core formation. However, since Cu is more volatile than Ni and Co, and Pb is more volatile than S, correction for Cu and Pb may cause overabundance of Ni, Co and S respectively. This puts a constraint on the lower limit of bulk Earth volatile abundances. It is found that bulk Earth must be less depleted in volatile elements than the volatility trend suggests (Figure 2).

Further studies is underway to investigate partitioning of lithophile elements sodium, potassium and cesium (Na, K, Cs) between lower mantle phases and silicate melt. We will examine the possibility of these elements entering lower mantle during mantle differentiation, in order to understand their depletion in the upper mantle (on volatility trend) relative to the bulk Earth volatile composition

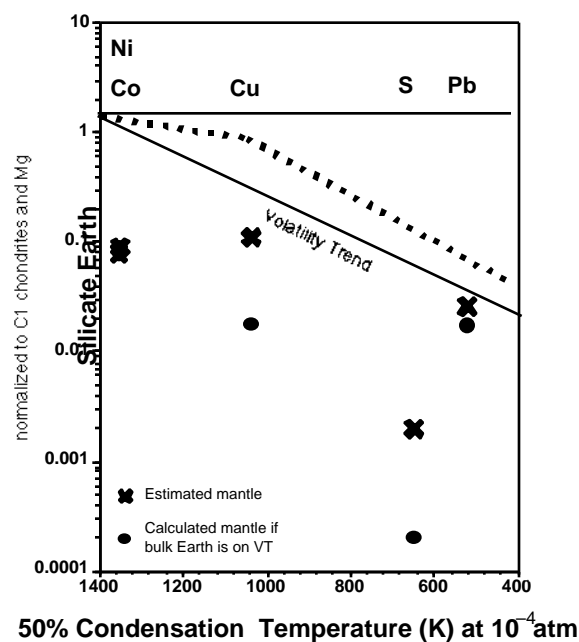suggested by volatile siderophile elements (above volatility trend).

Figure 2. Comparison between estimated mantle abundances of Ni, Co, Cu, S and Pb and those calculated for core-mantle equilibrium at mid-mantle pressure (~30 GPa), assuming bulk Earth falls on volatility trend. Dashed line represents the lower limit of bulk Earth Volatile abundances (see text).

References
[1] Li and Agee, Nature, 381, 686-689, 1996.
[2] Agee et al, J. Geophys. Res. 100, 17,725 - 17,740, 1995.